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(54) **FRAMEWORK FOR TRAFFIC ENGINEERING IN SOFTWARE DEFINED NETWORKING**

(71) Applicant: **Huawei Technologies Co., Ltd.**, Shenzhen (CN)

(72) Inventors: **Xu Li**, Nepean (CA); **Hamid Farmanbar**, Ottawa (CA); **Hang Zhang**, Nepean (CA)

(73) Assignee: **HUAWEI TECHNOLOGIES CO., LTD.**, Shenzhen (CN)

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  CPC H04L 45/42
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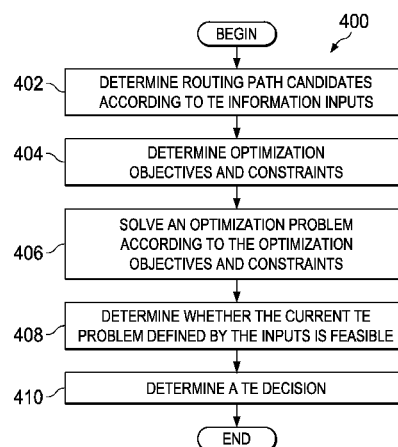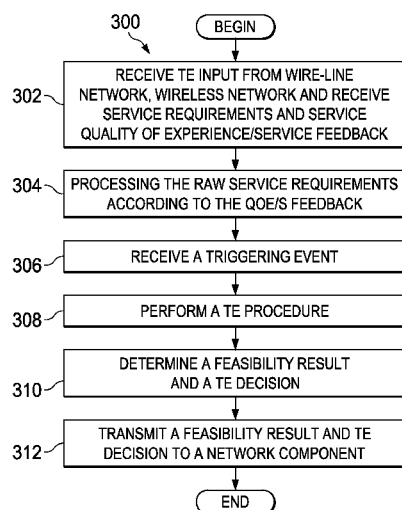*Primary Examiner* — Maharishi Khirodhar
(74) *Attorney, Agent, or Firm* — Slater & Matsil, L.L.P.

(57)   **ABSTRACT**

System and method embodiments are provided for traffic engineering (TE) in software defined networking (SDN). The embodiments enable a complete end-to-end TE solution between a user equipment (UE) and a source/destination across a radio access network (RAN). In an embodiment, a method in a network component for TE in a SDN includes receiving TE information from a first core network component in a core network, a RAN component, wherein the RAN is communicably coupled to the core network, wherein the TE information includes a TE objective; and determining a TE decision between at least one UE and a second core network component in the core network according to the TE information and the TE objective, wherein the TE decision comprises information for at least one end-to-end path solution between the at least one UE and the second core network wherein the path traverses the core network and the RAN.

34 Claims, 4 Drawing Sheets

300

BEGIN

302 — RECEIVE TE INPUT FROM WIRE-LINE NETWORK, WIRELESS NETWORK AND RECEIVE SERVICE REQUIREMENTS AND SERVICE QUALITY OF EXPERIENCE/SERVICE FEEDBACK

304 — PROCESSING THE RAW SERVICE REQUIREMENTS ACCORDING TO THE QOE/S FEEDBACK

306 — RECEIVE A TRIGGERING EVENT

308 — PERFORM A TE PROCEDURE

310 — DETERMINE A FEASIBILITY RESULT AND A TE DECISION

312 — TRANSMIT A FEASIBILITY RESULT AND TE DECISION TO A NETWORK COMPONENT

END

400

BEGIN

402 — DETERMINE ROUTING PATH CANDIDATES ACCORDING TO TE INFORMATION INPUTS

404 — DETERMINE OPTIMIZATION OBJECTIVES AND CONSTRAINTS

406 — SOLVE AN OPTIMIZATION PROBLEM ACCORDING TO THE OPTIMIZATION OBJECTIVES AND CONSTRAINTS

408 — DETERMINE WHETHER THE CURRENT TE PROBLEM DEFINED BY THE INPUTS IS FEASIBLE

410 — DETERMINE A TE DECISION

END

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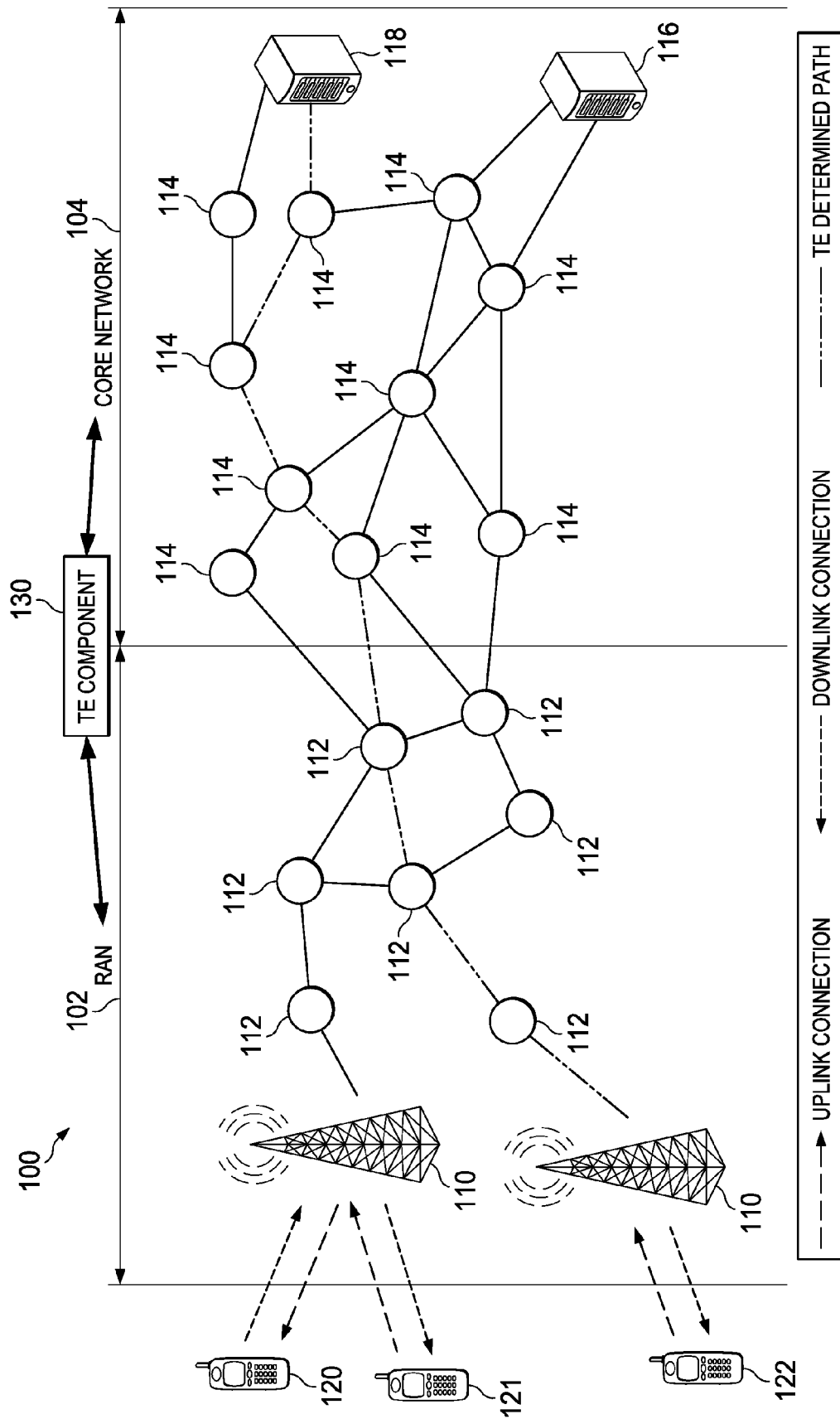International Search Report and Written Opinion of the International Searching Authority received in Patent Cooperation Treaty Application No. PCT/US2015/010340 mailed May 1, 2015, 9 pages.
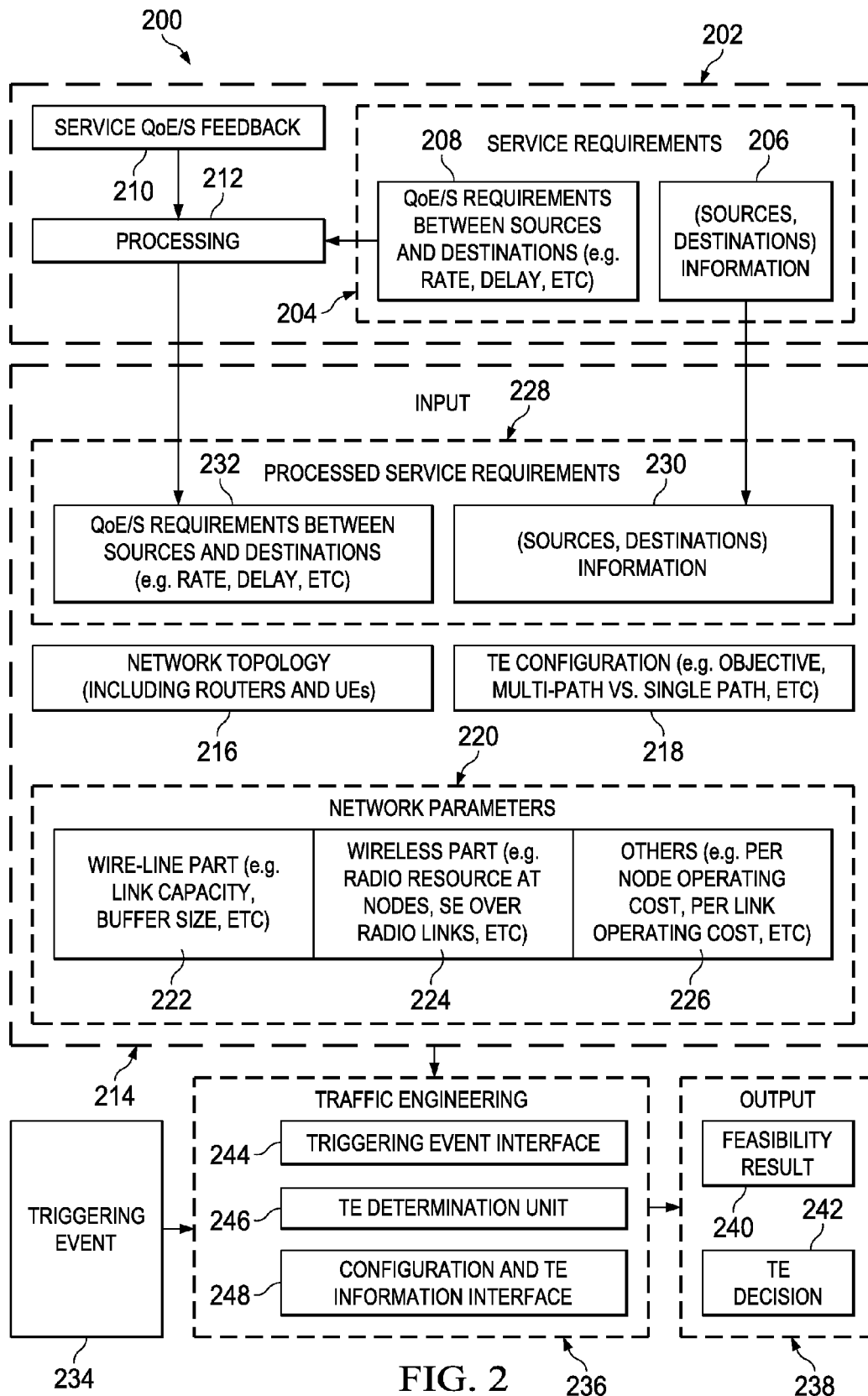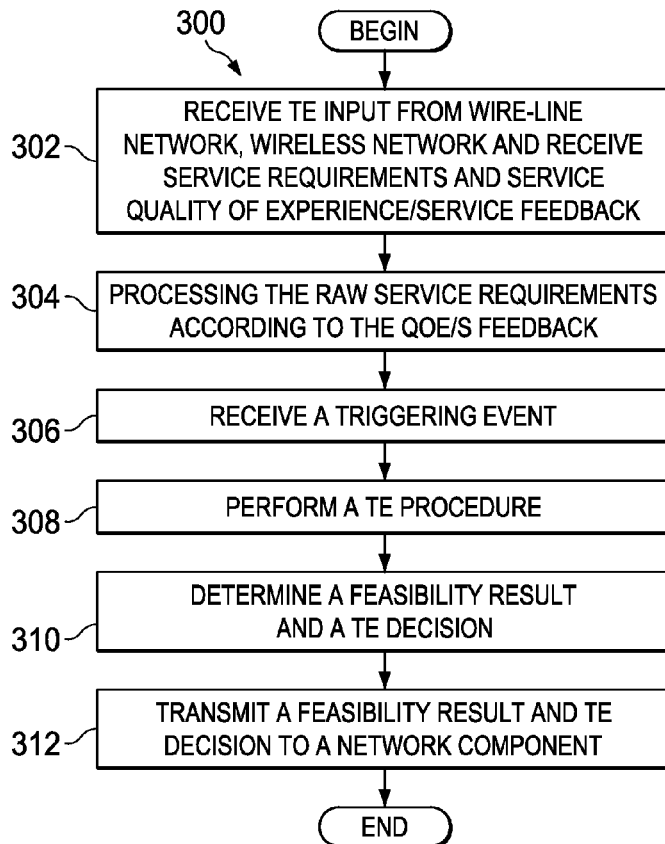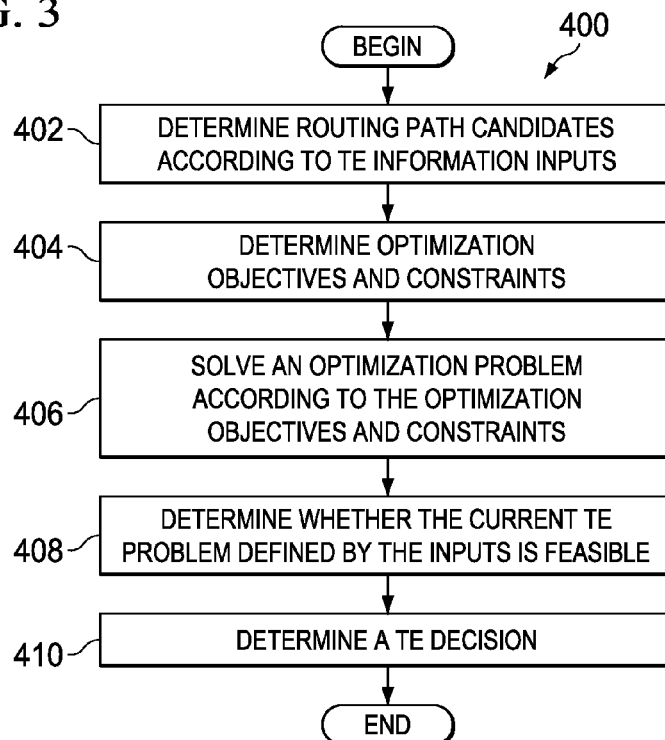
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FIG. 1

200

202

SERVICE QoE/S FEEDBACK

208   SERVICE REQUIREMENTS   206

210

212

QoE/S REQUIREMENTS BETWEEN SOURCES AND DESTINATIONS (e.g. RATE, DELAY, ETC)

(SOURCES, DESTINATIONS) INFORMATION

PROCESSING

204

INPUT   228

232   PROCESSED SERVICE REQUIREMENTS   230

QoE/S REQUIREMENTS BETWEEN SOURCES AND DESTINATIONS (e.g. RATE, DELAY, ETC)

(SOURCES, DESTINATIONS) INFORMATION

NETWORK TOPOLOGY (INCLUDING ROUTERS AND UEs)

TE CONFIGURATION (e.g. OBJECTIVE, MULTI-PATH VS. SINGLE PATH, ETC)

216

220

218

NETWORK PARAMETERS

WIRE-LINE PART (e.g. LINK CAPACITY, BUFFER SIZE, ETC)	WIRELESS PART (e.g. RADIO RESOURCE AT NODES, SE OVER RADIO LINKS, ETC)	OTHERS (e.g. PER NODE OPERATING COST, PER LINK OPERATING COST, ETC)

222

224

226

214

TRAFFIC ENGINEERING

OUTPUT

244 — TRIGGERING EVENT INTERFACE

FEASIBILITY RESULT

TRIGGERING EVENT

246 — TE DETERMINATION UNIT

240   242

248 — CONFIGURATION AND TE INFORMATION INTERFACE

TE DECISION

234

FIG. 2   236

238

300

BEGIN

302 — RECEIVE TE INPUT FROM WIRE-LINE NETWORK, WIRELESS NETWORK AND RECEIVE SERVICE REQUIREMENTS AND SERVICE QUALITY OF EXPERIENCE/SERVICE FEEDBACK

304 — PROCESSING THE RAW SERVICE REQUIREMENTS ACCORDING TO THE QOE/S FEEDBACK

306 — RECEIVE A TRIGGERING EVENT

308 — PERFORM A TE PROCEDURE

310 — DETERMINE A FEASIBILITY RESULT AND A TE DECISION

312 — TRANSMIT A FEASIBILITY RESULT AND TE DECISION TO A NETWORK COMPONENT

END

FIG. 3

BEGIN   *400*

402 — DETERMINE ROUTING PATH CANDIDATES ACCORDING TO TE INFORMATION INPUTS

404 — DETERMINE OPTIMIZATION OBJECTIVES AND CONSTRAINTS

406 — SOLVE AN OPTIMIZATION PROBLEM ACCORDING TO THE OPTIMIZATION OBJECTIVES AND CONSTRAINTS

408 — DETERMINE WHETHER THE CURRENT TE PROBLEM DEFINED BY THE INPUTS IS FEASIBLE

410 — DETERMINE A TE DECISION

END

FIG. 4

FIG. 5

FRAMEWORK FOR TRAFFIC ENGINEERING IN SOFTWARE DEFINED NETWORKING

TECHNICAL FIELD

The present invention relates to a system and method for software defined networking, and, in particular embodiments, to a system and method for traffic engineering in software defined networking.

BACKGROUND

Software defined networking (SDN) decouples traffic management (i.e., the control plane) from traffic forwarding (i.e., the data plane). In the control plane, SDN manages the network resources (e.g., how to use them) and the control network traffic flows (e.g., where to send them) jointly by a central SDN controller. Traffic flows have diversified Quality of Experience (QoE) and Quality of Service (QoS) requirements (e.g., rate, delay, delay jitter, outage, buffering time, etc.), depending on their nature (e.g., video) and/or application (e.g., video conferencing or downloading, etc.). The SDN controller has the responsibility to engineer traffic, that is, to plan routes for traffic flows and allocate resources (e.g., capacity, spectrum, power, etc.) along the routes, jointly so that their Quality of Experience/Service (QoE/S) requirements are met efficiently and effectively. This is normally an optimization problem.

SUMMARY

In accordance with an embodiment, a method in a network component for traffic engineering (TE) in a software defined network (SDN) includes receiving TE information from a first core network component in a core network, a radio access network (RAN) component, wherein the RAN is communicatively coupled to the core network, and wherein the TE information includes a TE objective; and determining a TE decision between at least one UE and a second core network component in the core network according to the TE information and the TE objective, wherein the TE decision comprises information for at least one end-to-end path solution between the at least one UE and the second core network wherein the path traverses the core network and the RAN.

In accordance with an embodiment, a network component configured for traffic engineering (TE) in a software defined network (SDN) includes a processor and a computer readable storage medium storing programming for execution by the processor, the programming including instructions to: receive TE information from a first core network component in a core network, a radio access network (RAN) component, wherein the RAN is communicably coupled to the core network, and wherein the TE information includes a TE objective; and determine a TE decision between at least one UE and a second core network component in the core network according to the TE information and the TE objective, wherein the TE decision comprises information for at least one end-to-end path solution between the at least one UE and the second core network wherein the path traverses the core network and the RAN.

In accordance with an embodiment, a traffic engineering (TE) component in a software defined network (SDN) includes a first interface connected to at least one control/management component to receive TE information about a wireline network and a radio access network (RAN) and to receive TE configuration information; a second interface con-

figured to receive a triggering event from one of the wireline network and the RAN; and a TE decision component connected to the first and second interfaces configured to determine a unified TE determination in response to the triggering event according to the TE information and TE configuration information, wherein the unified TE determination comprises a path selection between a source and destination for a plurality of source-destination pairs in the RAN and the core network and a rate allocation over selected paths for the plurality of source-destination pairs in the RAN and core network.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawing, in which:

FIG. 1 illustrates a network for communicating data;

FIG. 2 illustrates an embodiment of a TE framework;

FIG. 3 illustrates an embodiment method for a TE feasibility and decision determination;

FIG. 4 illustrates an embodiment TE procedure 400; and

FIG. 5 illustrates a computing platform that may be used for implementing, for example, the devices and methods described herein, in accordance with an embodiment.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

The making and using of the presently preferred embodiments are discussed in detail below. It should be appreciated, however, that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed are merely illustrative of specific ways to make and use the invention, and do not limit the scope of the invention.

Existing traffic engineering (TE) solutions consider aggregate traffic in the core network and do not consider radio access networks (RAN). Furthermore, existing TE solutions are not designed for cellular networks. However, handling core networks and RAN jointly will clearly improve system performance.

Disclosed herein are systems and methods for per service traffic management that consider wireless access networks and UEs in addition to the core wired network components in making a TE decision. A service is defined by the logical data plane topology (obtained from other components) In an embodiment, the logical data plane topology includes source info (multiple sources are possible), destination info (multiple sinks are possible), and link QoE/S (e.g. throughput, etc.) requirements from sources to destinations.

Also disclosed herein is a traffic engineering (TE) framework that defines TE interface (input and output), defines a service requirement processing component, and adjusts service requirements according to service QoE/S feedback before inputting them into TE. For example, to reduce the rate requirement of a logical link with very high QoE performance in the past so that network resources can be used to satisfy logical links experiencing low QoE. Embodiments of the TE framework provide a unified TE decision, include user equipment (UEs) as part of network topology, and handle all network entities (whether wire-line or wireless) together. Embodiments of the TE framework include the mechanisms for per service management, TE interface, service requirement processing component, TE procedure, and a unified TE decision.

In an embodiment, a TE component collects TE information from a variety of network components in both the core network (i.e., wired network) and a radio access network (i.e., the wireless network) and provides a TE decision that encompasses an end-to-end solution from, for example, wireless user equipment to a network server in the core network. In an embodiment, the TE component is an SDN controller. However, the TE component may be implemented in other network components in other embodiments. The TE information may include network topology, including routers and user equipment (UEs), TE configuration (e.g., TE objective, multipath vs. single path, etc.), link capacity and buffer size of wire-line part, radio resources at nodes and spectral efficiency (SE) values over radio links for the wireless part, per node operating cost, per link operating cost, source and destination information, QoE/S requirements between sources and destinations (e.g., rate, delay, etc.), and QoE/S feedback. SE is measured in bits/second/HZ. The SE value of a wireless access link indicates link quality and depends on radio transmission configuration at all access nodes. In an embodiment, the TE component computes a feasibility result and a TE decision based on the TE information received as inputs in response to receiving a triggering event. Examples of a triggering event include a one-time time out event, a periodic time out event, and input change event, and a service QoE/S performance degradation event. Examples of an input change event include a network topology change (e.g., node (router or UE) addition/removal), a network parameter change (e.g., a link SE change, a radio resource availability change, a link capacity change, a buffer size change, an operating cost change, etc.), and a service requirement (logical data plane topology) change (e.g., source/destination addition/removal, logical link (source to destination) QoE/S requirement change, etc.). The feasibility result is an indication of whether the current TE problem (defined by all the inputs) is feasible. The TE decision provides, for example, end-to-end paths (routes), per route resource/rate allocation, etc. or links used for end-to-end routing, per link resource/rate allocation, etc.

In an embodiment, a method in a network component for traffic engineering (TE) in a software defined network (SDN), includes identifying a TE objective, receiving TE information from a first core network component in a core network, a radio access network (RAN) component connected to the core network, wherein the RAN is communicatively coupled to the core network, and wherein the TE information includes a TE objective, and determining a TE decision between the UE and a second core network component in the core network according to the TE information and the TE objective, wherein the TE decision includes information for at least one end-to-end path solution between the UE and the second core network wherein the path traverses the core network and the RAN. In an embodiment, the TE decision includes path selection between a source and destination for a plurality of source-destination pairs in the network as well as rate allocation over selected paths for all source-destination pairs in the network, where the network includes both the RAN and a core network. In an embodiment, determining a TE decision between the UE and a second core network component is performed in response to a triggering event. The triggering event may include a network topology change, a network parameter change, a service requirement change, and a service quality of experience or quality of service performance degradation event. The network topology change may include a node addition or removal. The network parameter change includes at least one of a radio resource availability change, a link capacity change, a buffer size change, an operating cost change, and a link SE change. The service requirement

change includes at least one of a source addition, destination addition, a source removal, a destination removal, a logical link quality of experience requirement change, and a logical link quality of service requirement change. The TE decision may include an end-to-end path, a per route resource allocation, a per route rate allocation, links used for end-to-end routing, per link resource allocation, and per link rate allocation. In an embodiment, the TE method includes adjusting a path computation algorithm or process according to a change in traffic engineering configuration parameters. For example, if the TE configuration explicitly specifies what path computation algorithm is to be used, then when the configuration changes or the specified algorithm changes, the adjustment to the path computation algorithm used by the TE is made. The traffic engineering information may include quality of experience requirements between sources and destinations and quality of service requirements between sources and destinations, a rate requirement, a delay requirement, a quality of experience feedback, quality of service feedback, and network parameters. The network parameters may include link capacity, buffer size, radio resources at RAN nodes, per node operating cost, and per link operating cost.

FIG. 1 illustrates a network 100 for communicating network. The network 100 includes a RAN 102, a core network 104, and a TE component 130 in communication with one or more components in each of the RAN 102 and the core network 104. The core network 104 and the RAN 102 may comprise a software defined network (SDN). In an embodiment, the TE component 130 may be implemented within one of the core nodes 114 in the core network 104 or one of the RAN nodes 112 in the RAN 102. In an embodiment, the TE component is a logical component and can be implemented on one physical node or in a distributed manner on multiple physical nodes. The RAN 102 includes a plurality of RAN nodes 112 and wireless access points (APs) 110. A plurality of user equipment (UEs) 120, 121, 122 are wirelessly connected to the APs 110. As used herein, the term AP may also be referred to as a transmission point (TP), a base station (BS), or a base transceiver station (BTS) and the four terms may be used interchangeably throughout this disclosure. The APs 110 each may comprise any component capable of providing wireless access by, inter alia, establishing uplink (UL) (dashed line) and/or downlink (DL) (dotted line) connections with the UEs 120, 121, 122, such as a BTS, an enhanced base station (eNB), a femtocell, and other wirelessly enabled devices. The UEs 120, 121, 122 may comprise any component capable of establishing a wireless connection with the APs 110. Examples of UEs include smart phones, tablet computers, and laptops. The RAN nodes 112 connect or otherwise communicably couple the APs 110 to the core network 104. The connections between the RAN nodes 112 may include wired and wireless connections. The RAN nodes 112 may include routers, switches, and gateways.

The core network 104 includes a plurality of core nodes 114 and end point servers 116, 118. In an embodiment, the core network 104 may be the Internet, a local area network (LAN), or a wide area network (WAN). Connections between the core nodes 114 are wired or physical connections, such as fiber optic cables. Examples of core nodes 114 include routers, switches, and servers. Each core node 114 is capable of receiving data from other nodes and transmitting or forwarding data to other nodes.

The TE component 130 includes an interface to other control/management components within the core network 104 and/or the RAN 102. TE component 130 receives TE information from various nodes 112, 114 in the RAN 102 and the core network 104 and provides TE determinations to the

nodes **112, 114**. In an embodiment, the TE information includes information about both the RAN **102**, the core network **104**, and the UEs **120, 121, 122**. The TE information may include network topology information, which includes routers and UEs in the topology. The TE information may also include TE configuration information, such as, for example, a TE objective, multipath vs. single path information, etc. TE information includes network parameters concerning the core network **104** (i.e., wire-line part), the RAN **102** (i.e., wireless part), as well as other network parameters. The core network **104** (i.e., wire-line) part of the network parameters include information, such as, for example, link capacity and buffer size. The RAN **102** (i.e., wireless) part of the network parameters includes information, such as radio resources at nodes **112**, SE over radio links, etc. Other network parameters include per node operating cost, per link operating cost, etc. Other information collected by the TE component **130** include information regarding sources and destinations of data, quality of experience and quality of service (QoE/S) requirement between sources and destinations (e.g., rate, delay, etc.), and service QoE/S feedback.

The TE component **130** computes a feasibility result and a TE decision from the inputs in response to a triggering event. In an embodiment, the TE decision includes end-to-end paths (routes), per route resource and rate allocation. In a second embodiment, the TE decision includes links used for end-to-end routing, and/or per link resource/rate allocation. In a third embodiment, the TE decision includes a mixture of the information included in the first and second embodiments discussed above. The TE component **103** may compute multiple paths or a single path. TE determined path (represented by the dashed-dotted line in FIG. **1**) is an example of one path from/to UE **122** to/from a server **118** across both the RAN **102** and the core network **104** determined by the TE component **130**. In an embodiment, the TE component **130** also computes a feasibility result indicating whether a current TE problem as defined by all of the inputs is feasible or not. In an embodiment, TE functionality does not change as a result of infeasibility. Rather, the TE decision still finds paths for all source-destination pairs and finds allocation for all paths. Infeasibility is just an indication that the rate allocation resulting from the TE determination cannot fully satisfy all user QoE requirements.

FIG. **2** illustrates an embodiment of a TE framework **200**. TE framework includes a TE component **236** that receives input **214** and computes an output **238** in response to a triggering event. TE component **236** may be implemented as TE component **130** in FIG. **1**. The input includes network topology inputs **216**, TE configuration inputs **218**, network parameters **220**, and processed service requirements **228**. Examples of network topology inputs **216** include location, identity, and performance capabilities of routers, switches, UEs, and other similar components. Examples of TE configuration inputs **218** include a TE objective, an indication of whether a multipath or a single path should be computed, etc. The network parameters **220** include wire-line part parameters **222**, wireless part parameters **224**, and other network parameters **226**. Wire-line part parameters **222** include, for example, link capacity, buffer size, etc. Wireless part parameters **224** include, for example, radio resources at nodes, SE over radio links, etc. Other network parameters **226** include per node operating cost, per link operating cost, etc.

Processed service requirements **228** receives source and destination information **230** from a source and destination information element **206** in service processing unit **202**. Processed service requirements **228** also receives QoE/S requirements between sources and destinations **232** from a process-

ing unit **212** in the service processing unit **202**. The service processing unit **202** includes a service requirements component **204** that collects and/or stores service requirements. The service requirements include source and destination information **206** and QoE/S requirements between sources and destinations **208**. Examples of QoE/S requirements include rate, delay, etc. The service processing unit **202** also receives service QoE/S feedback **210** and processes the feedback **210** along with the QoE/S requirements **208** in a processing unit **212**. The service processing unit **202** determines the QoE/S input to the TE component **236** based on the raw QoE/S requirements and the QoE/S feedback. For example, it may reduce the rate requirement (as QoE/S requirement) of a logical link with very high QoE/S performance in the past so that the network resources can be used to satisfy logical links experiencing low QoE/S. The results of the processing are provided as part of the processed service requirements **228** used as input to the TE component **236**.

In response to a triggering even **234**, the TE component **236** uses the input **214** to determine an output **238**. The output **238** includes a feasibility result **240** and a TE decision. Examples of a triggering event **234** include a time out event (one time or periodic time out event), an input change event, a service QoE/S performance degradation event. Examples of an input change event include a network topology change (e.g., node (router or UE) addition/removal), network parameter change (e.g., link SE change, radio resource availability change, link capacity change, buffer size change, operating cost change, etc.), and service requirement (logical data plane topology) change (e.g., source/destination addition/removal, logical link (source to destination) QoE/S requirement change).

The TE component **236** includes a configuration and TE information interface to receive configuration and TE input from various components (e.g., controllers, management components, nodes, etc.), a triggering event interface **244** to receive triggering event information from various components in a wireless (e.g., RAN) or wired network, and a TE determination unit **246** that determines a feasibility result **240** and a TE decision **242**.

To determine a feasibility result and/or a TE decision, the TE component **236** performs a TE procedure. In an embodiment, the TE component **236** determines routing path candidates. To determine routing path candidates, the TE component **236** finds a maximum number of candidate routing paths for each logical link (source-destination). The maximum number of candidate routing paths may be pre-computed or computed in real time by the TE component **236**.

In an embodiment, the TE component **236** solves an optimization problem in order to produce a TE decision **242**. The optimization problem includes an optimization objective that is obtained from the TE configuration **218**, network parameter based constraints, service requirement constraints, and other constraints. Network parameter based constraints include wire-line link capacity constraints, wireless access node resource constraints, per node/link operating cost constraints, etc. The cost constraints may be, for example, power consumption. The service requirements constraints include logical link rate (throughput) constraints, logical link delay constraints, etc. Other constraints include, for example, the number of routing paths per logical link, etc. The feasibility result **240** produced by the TE component **236** provides an indication of whether the current TE problem as defined by all the inputs is feasible. In an embodiment, the TE feasibility result **240** is a byproduct of solving the TE problem. Regardless of whether the TE problem is feasible, the TE component **240** determines a TE decision **242**. However, if the TE problem is infeasible, the TE decision **242** may not satisfy all of

the flow requirements (e.g., user QoE requirements, QoS requirements, etc.) for all flows. When full satisfaction is impossible, TE can partially satisfy flows. The TE decision **242** may include one or more end-to-end paths (routes), per route resource/rate allocation, etc. In an embodiment, the TE decision **242** may include links used for end-to-end routing, per link resource/rate allocation, etc. The TE decision **242** output is provided to routers and access nodes in the RAN and core network such that traffic is forwarded at each node according to the TE decision **242**. In an embodiment, the TE component **246** may also provide the TE feasibility result to a controller so that the controller may take appropriate control actions.

In an example TE procedure performed by the TE component **236**, the input to the TE component **236** includes TE configuration information, including a weighted maximum minimum objective, max λ, and the maximum number of paths per logical link, m. The input also includes service requirement of the logical links (source-destination) and per logical link rate/throughput demand, d_k where d_k is the rate/throughput demand for link k. Additionally, the input includes wire-line link capacities, c_e, where c_e is the capacity for wired link e, wireless access node resources, r_n, where r_n is the wireless access node resource for node n, and wireless link SE, s_{path}^n, where s_{path}^n is the wireless link SE for the wireless access link of n on path. The output is a feasibility result λ, where the TE problem is feasible if $\lambda \geq 1$ and infeasible otherwise. The output also includes a TE decision that provides routing paths for every logical link k and a rate allocation, x_j^k, on the j-th routing path of logical link k. The TE procedure includes determining routing path candidates by running m shortest path routing algorithm for each logical link. Every logical link, k, than has $l_k \leq m$ number of candidate paths, p_j^k, j=1, 2, . . . , l_k. The TE component **236** then soles the following optimization problem (weighted Max Min fairness):

The objective function→max λ

Service requirement constraints→$\Sigma_{j=1}^{l_k} x_j^k \geq \lambda d_k$, ∀ logical link k

only rate/throughput is considered

Wire-line link capacity constraints→$\Sigma_{path\ p_j^k passing\ link\ e} x_j^k \leq c_e$, ∀ wired link e

Wireless access node resource constraints→

$$\sum_{path\ p_j^k using\ n} \frac{x_j^k}{s_{p_j^k}^n} \leq r_n,$$

∀ wireless access node n

Candidate paths (determined previously)→p_j^k, j=1, 2, . . . , l_k, ∀ logical link k.

FIG. **3** illustrates an embodiment method **300** for a TE feasibility and decision determination. The method **300** begins at block **302** where the TE component receives TE input from a wire-line network, a wireless network, and receives service requirements and service QoE/S feedback. At block **304**, the raw service requirements are processed according to the QoE/S feedback. At block **306**, the TE component receives a triggering event causing the TE component to implement a TE procedure at block **308**. In an embodiment, the TE procedure solves an optimization problem based on the input. At block **310**, the TE component determines a feasibility result and a TE decision from the TE procedure. At

block **312**, the feasibility result and/or TE decision is transmitted to a network component, after which, the method **300** ends.

FIG. **4** illustrates an embodiment TE procedure **400**. TE procedure **400** is an example of TE procedure **308** in FIG. **3**. TE procedure **400** begins at block **402** where the TE component determines routing path candidates according to TE information inputs. At block **404**, the TE component determines optimization objective(s) and constraint(s). At block **406**, the TE component solves an optimization problem according to the optimization objective(s) and constraint(s). At block **408**, the TE component determines whether the current TE problem defined by the inputs is feasible and at block **410**, the TE component determines a TE decision, after which the TE procedure **400** ends.

FIG. **5** is a block diagram of a processing system **500** that may be used for implementing the devices and methods disclosed herein. Specific devices may utilize all of the components shown, or only a subset of the components and levels of integration may vary from device to device. Furthermore, a device may contain multiple instances of a component, such as multiple processing units, processors, memories, transmitters, receivers, etc. The processing system **500** may comprise a processing unit **501** equipped with one or more input/output devices, such as a speaker, microphone, mouse, touchscreen, keypad, keyboard, printer, display, and the like. The processing unit **501** may include a central processing unit (CPU) **510**, memory **520**, a mass storage device **530**, a network interface **550**, an I/O interface **560**, and an antenna circuit **570** connected to a bus **540**. The processing unit **501** also includes an antenna element **575** connected to the antenna circuit.

The bus **540** may be one or more of any type of several bus architectures including a memory bus or memory controller, a peripheral bus, video bus, or the like. The CPU **510** may comprise any type of electronic data processor. The memory **520** may comprise any type of system memory such as static random access memory (SRAM), dynamic random access memory (DRAM), synchronous DRAM (SDRAM), read-only memory (ROM), a combination thereof, or the like. In an embodiment, the memory **520** may include ROM for use at boot-up, and DRAM for program and data storage for use while executing programs.

The mass storage device **530** may comprise any type of storage device configured to store data, programs, and other information and to make the data, programs, and other information accessible via the bus **540**. The mass storage device **530** may comprise, for example, one or more of a solid state drive, hard disk drive, a magnetic disk drive, an optical disk drive, or the like.

The I/O interface **560** may provide interfaces to couple external input and output devices to the processing unit **501**. The I/O interface **560** may include a video adapter. Examples of input and output devices may include a display coupled to the video adapter and a mouse/keyboard/printer coupled to the I/O interface. Other devices may be coupled to the processing unit **501** and additional or fewer interface cards may be utilized. For example, a serial interface such as Universal Serial Bus (USB) (not shown) may be used to provide an interface for a printer.

The antenna circuit **570** and antenna element **575** may allow the processing unit **501** to communicate with remote units via a network. In an embodiment, the antenna circuit **570** and antenna element **575** provide access to a wireless wide area network (WAN) and/or to a cellular network, such as Long Term Evolution (LTE), Code Division Multiple Access (CDMA), Wideband CDMA (WCDMA), and Global System for Mobile Communications (GSM) networks. In

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some embodiments, the antenna circuit **570** and antenna element **575** may also provide Bluetooth and/or WiFi connection to other devices.

The processing unit **501** may also include one or more network interfaces **550**, which may comprise wired links, such as an Ethernet cable or the like, and/or wireless links to access nodes or different networks. The network interface **501** allows the processing unit **501** to communicate with remote units via the networks **580**. For example, the network interface **550** may provide wireless communication via one or more transmitters/transmit antennas and one or more receivers/receive antennas. In an embodiment, the processing unit **501** is coupled to a local-area network or a wide-area network for data processing and communications with remote devices, such as other processing units, the Internet, remote storage facilities, or the like.

Although the description has been described in detail, it should be understood that various changes, substitutions and alterations can be made without departing from the spirit and scope of this disclosure as defined by the appended claims. Moreover, the scope of the disclosure is not intended to be limited to the particular embodiments described herein, as one of ordinary skill in the art will readily appreciate from this disclosure that processes, machines, manufacture, compositions of matter, means, methods, or steps, presently existing or later to be developed, may perform substantially the same function or achieve substantially the same result as the corresponding embodiments described herein. Accordingly, the appended claims are intended to include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or steps.

What is claimed is:

1. A method in a network component for traffic engineering (TE) in a software defined network (SDN), the method comprising:

receiving, by a TE component, a first TE information from a first core network component in a core network;

receiving, by the TE component, a second TE information from a radio access network (RAN) component in a RAN; and

transmitting, by the TE component, a TE decision to a plurality of network components, wherein the TE decision is associated with a TE configuration, the first TE information, and the second TE information, wherein the TE configuration comprises a TE objective, and wherein the TE decision comprises information for a solution for multiple end-to-end paths between at least one user equipment (UE) and a second core network component in the core network, wherein a plurality of the multiple end-to-end paths are to be used by one of the UEs simultaneously, and wherein each of the multiple end-to-end paths traverses the core network and the RAN.

2. The method of claim **1**, wherein the TE information comprises spectral efficiency (SE) values over radio links.

3. The method of claim **1**, further comprising determining a feasibility result indicating whether a current TE problem defined by the TE information is feasible.

4. The method of claim **1**, wherein the determining a TE decision between the at least one UE and a second core network component is performed in response to a triggering event.

5. The method of claim **4**, wherein the triggering event comprises at least one of a network topology change, a network parameter change, a service requirement change, and a service quality of experience or quality of service performance degradation event.

6. The method of claim **5**, wherein the network topology change comprises a node addition or removal.

7. The method of claim **5**, wherein the network parameter change comprises at least one of a radio resource availability change, a link capacity change, a buffer size change, an operating cost change, and a link SE change.

8. The method of claim **5**, wherein the service requirement change comprises at least one of a source addition, destination addition, a source removal, a destination removal, a logical link quality of experience requirement change, and a logical link quality of service requirement change.

9. The method of claim **1**, wherein the TE decision comprises at least one of an end-to-end path, a per route resource allocation, a per route rate allocation, links used for end-to-end routing, per link resource allocation, and per link rate allocation.

10. The method of claim **1**, further comprising adjusting a path computation algorithm according to a change in traffic engineering configuration parameter.

11. The method of claim **1**, wherein the traffic engineering information comprise at least one of quality of experience requirements between sources and destinations and quality of service requirements between sources and destinations.

12. The method of claim **1**, wherein the traffic engineering information comprise at least one of a rate requirement and a delay requirement.

13. The method of claim **1**, wherein the traffic engineering information comprises at least one of quality of experience feedback and quality of service feedback.

14. The method of claim **1**, wherein the traffic engineering information comprises network parameters.

15. The method of claim **14**, wherein the network parameters comprise at least one of link capacity, buffer size, radio resources at RAN nodes, per node operating cost, and per link operating cost.

16. A network component configured for traffic engineering (TE) in a software defined network (SDN), the network component comprising:

a processor; and

a non-transitory computer readable storage medium storing programming for execution by the processor, the programming including instructions to:

receive a first TE information from a first core network component in a core network;

receive a second TE information from a radio access network (RAN) component in a RAN; and

transmit a TE decision to a plurality of network components, wherein the TE decision is associated with a TE configuration, the first TE information, and the second TE information, wherein the TE configuration comprises a TE objective, and wherein the TE decision comprises information for a solution for multiple end-to-end paths between at least one user equipment (UE) and a second core network component in the core network, wherein a plurality of the multiple end-to-end paths are to be used by one of the UEs simultaneously, and wherein each of the multiple end-to-end paths traverses the core network and the RAN.

17. The network component of claim **16**, wherein the TE information comprises spectral efficiency (SE) values over radio links.

18. The network component of claim **16**, wherein the programming further comprises instructions to determine a feasibility result indicating whether a current TE problem defined by the TE information is feasible.

19. The network component of claim **16**, wherein the instructions to determine a TE decision between the at least

one UE and a second core network component is performed in response to a triggering event.

20. The network component of claim 19, wherein the triggering event comprises at least one of a network topology change, a network parameter change, a service requirement change, and a service quality of experience or quality of service performance degradation event.

21. The network component of claim 20, wherein the network topology change comprises a node addition or removal.

22. The network component of claim 20, wherein the network parameter change comprises at least one of a radio resource availability change, a link capacity change, a buffer size change, an operating cost change, and a link SE change.

23. The network component of claim 20, wherein the service requirement change comprises at least one of a source addition, destination addition, a source removal, a destination removal, a logical link quality of experience requirement change, and a logical link quality of service requirement change.

24. The network component of claim 16, wherein the TE decision comprises at least one of an end-to-end path, a per route resource allocation, a per route rate allocation, links used for end-to-end routing, per link resource allocation, and per link rate allocation.

25. The network component of claim 16, wherein the programming further comprises instructions to adjust a path computation algorithm according to a change in a traffic engineering configuration parameter.

26. The network component of claim 16, wherein the TE information comprise at least one of quality of experience requirements between sources and destinations and quality of service requirements between sources and destinations.

27. The network component of claim 16, wherein the TE information comprise at least one of a rate requirement and a delay requirement.

28. The network component of claim 16, wherein the TE information comprises at least one of quality of experience feedback and quality of service feedback.

29. The network component of claim 16, wherein the TE information comprises network parameters.

30. The network component of claim 29, wherein the network parameters comprise at least one of link capacity, buffer size, radio resources at RAN nodes, per node operating cost, and per link operating cost.

31. A traffic engineering (TE) component in a software defined network (SDN), comprising:

a first interface connected to at least one control/management component to receive a first TE information from a first core network component in a core network, to receive a second TE information from a radio access network (RAN) component in a RAN, and to receive TE configuration information;

a second interface configured to receive a triggering event from one of the core network and the RAN; and

a TE decision component, comprising a processor and non-transitory computer readable media, connected to the first and second interfaces that determines a unified TE decision in response to the triggering event according to the first TE information, the second TE information, and TE configuration information, wherein the TE configuration information comprises a TE objective, and wherein the unified TE decision comprises information for a solution for multiple end-to-end paths between at least one user equipment (UE) and a second core network component in the core network, wherein a plurality of the multiple end-to-end paths are to be used by one of the UEs simultaneously, and wherein each of the multiple paths traverses the core network and the RAN, and wherein the TE decision component is further configured to determine a rate allocation over the multiple end-to-end paths.

32. The TE component of claim 31, wherein the first interface is further configured to receive service requirements, wherein the service requirements include quality of experience and quality of service requirements between sources and destinations.

33. The TE component of claim 32, wherein the first interface is further configured to receive quality of experience and quality of service feedback.

34. The TE component of claim 31, wherein the triggering event comprises at least one of a network topology change, a network parameter change, a service requirement change, and a service quality of experience or quality of service performance degradation event.

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UNITED STATES PATENT AND TRADEMARK OFFICE
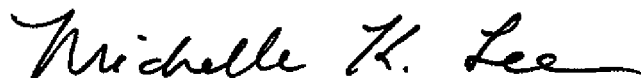# CERTIFICATE OF CORRECTION

PATENT NO.   : 9,225,652 B2   Page 1 of 1
APPLICATION NO.   : 14/097930
DATED   : December 29, 2015
INVENTOR(S)   : Xu Li

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page, Item (72) Inventors, line 1, delete "Hamid" and insert --Hamidreza--.

Signed and Sealed this
Nineteenth Day of April, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office

CERTIFICATE OF CORRECTION

PATENT NO.   : 9,225,652 B2   Page 1 of 1
APPLICATION NO.   : 14/097930
DATED   : December 29, 2015
INVENTOR(S)   : Farmanbar et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title Page, Item (12), line 2, delete "Li et al." and insert --Farmanbar et al.--.

On the Title Page, Item (72), Inventors, lines 1 and 2, delete "Xu Li, Nepean (CA); Hamid Farmanbar, Ottawa (CA);" and insert --Hamidreza Farmanbar, Ottawa (CA); Xu Li, Nepean (CA);--.

Signed and Sealed this
Second Day of August, 2016

Michelle K. Lee
Director of the United States Patent and Trademark Office